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The wave-tilt method of measuring electrical ground constants in the l.f. and m.f. bands

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THE WAVE-TILT METHOD OF MEASURING ELECTRICAL GROUND CONSTANTS IN THE LF AND MF BANDS

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Summary

The theory of the wave-tilt method of determining ground constants (conductivity and permittivity) at l.f. and m.f. is outlined and the limitations of the theory in practice is discussed. Typical instrumentation for conducting wave tilt measurements is mentioned and the effect of measurement errors assessed.

Issued under the authority of

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THE WAVE-TILT METHOD OF MEASURING ELECTRICAL GROUND CONSTANTS IN THE LF AND MF BANDS

J.L. Eaton, B.Sc., M.I.E.E.

1. Introduction

The wave-tilt method of measuring ground constants is based on the fact that, when a vertically polarised plane wave is propagating over flat ground, the surface impedance gives rise to a small radial component of the electric field vector. In general, the electric vector describes an ellipse in the plane containing the direction of propagation (viz: in the plane of the Poynting vector). The major axis of the ellipse is tilted forward to account for the flow of power into the surface of the ground. If it is possible to determine the forward tilt (relative to the surface) and the axial ratio of the ellipse with sufficient accuracy by measurement the ground constants (conductivity and permittivity) may be calculated directly from a known result.[1] The method has limitations but could be useful in certain circumstances as a means of performing checks on the results obtained by more general methods*. It has been suggested[2] that the method can be used for frequencies between 100 kHz and 40 MHz but most applications would be restricted to the l.f. and m.f. bands.

2. Theory

Assuming that the elliptical electric field is the resultant of two components E_s and E_n, parallel and normal to the surface of the ground respectively, it is easy to show that:

$$\left|\frac{E_s}{E_n}\right| = \sqrt{\frac{r^2 + \tan^2\theta}{1 + r^2\tan^2\theta}} \qquad (1)$$

and

$$\mathrm{Cos}\,(2\phi) = \frac{Y^2 - 4r^2}{Y^2 + 4r^2}, \quad Y = (1-r^2)\,\mathrm{Sin}\,(2\theta) \qquad (2)$$

where ϕ is the relative phase angle of the components, r = (minor axis)/(major axis) and θ is the forward tilt angle of the ellipse.

Now

$$\frac{E_s}{E_n} = \left|\frac{E_s}{E_n}\right| e^{j\phi}$$

where

$$\left|\frac{E_s}{E_n}\right| = \frac{1}{120\pi}\sqrt{\frac{\omega\mu}{\sqrt{\sigma^2 + \omega^2\epsilon^2}}}$$

and $\tan(2\phi) = \sigma/\omega\epsilon$

In the above expressions σ and ϵ are the absolute values of the ground constants in Siemen/m and Farad/m respectively; ω is the angular frequency and μ can be taken as the permeability of free space (Henry/m). It follows that the relative permittivity ϵ_r is given by:

$$\epsilon_r = \left|\frac{E_n}{E_s}\right|^2 \cos(2\phi) \qquad (3)$$

and the conductivity σ by

$$\frac{\sigma}{f} = \left|\frac{E_n}{E_s}\right|^2 \frac{\sin(2\phi)}{18}\ \mathrm{mS/m} \qquad (4)$$

when the frequency f is expressed in MHz.

Figure 1 shows the relationship between the dependent variables ϵ_r and σ/f in terms of θ between 0 and 16 degrees and r up to 0·25.

3. Limitations of the theory

The theory outlined in the previous section makes two fundamental assumptions:

(i) The ground is flat and homogeneous
(ii) There are no local obstacles to cause disturbance to the measured field.

In practice the method will fail if it is applied in the neighbourhood of an abrupt change in ground constants (for example at a coast line). If the ground is irregular, even if the constants are assumed to have fixed values, it is not immediately obvious how to proceed in order to get the best possible estimates.

The general situation may be illustrated qualitatively by expressing the "scattered" electric field at a point of observation just above the ground as a surface integral over the ground of retarded field components (the total field comprises the sum of a "scattered" component and a component due to a current distribution associated with the source). Let **E** be the "scattered" component then:[3]

$$\mathbf{E} = -\frac{j\omega\mu}{4\pi}\int_S \frac{[\mathrm{E_s}]}{Z_s}.\frac{1}{d}.\,ds + \frac{1}{4\pi}\int_S \left[\mathrm{n.\,E}\right]\left(\frac{1}{d^2} + \frac{jk}{d}\right)\nabla d.\,ds.$$

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* In particular the ground-wave attenuation method.

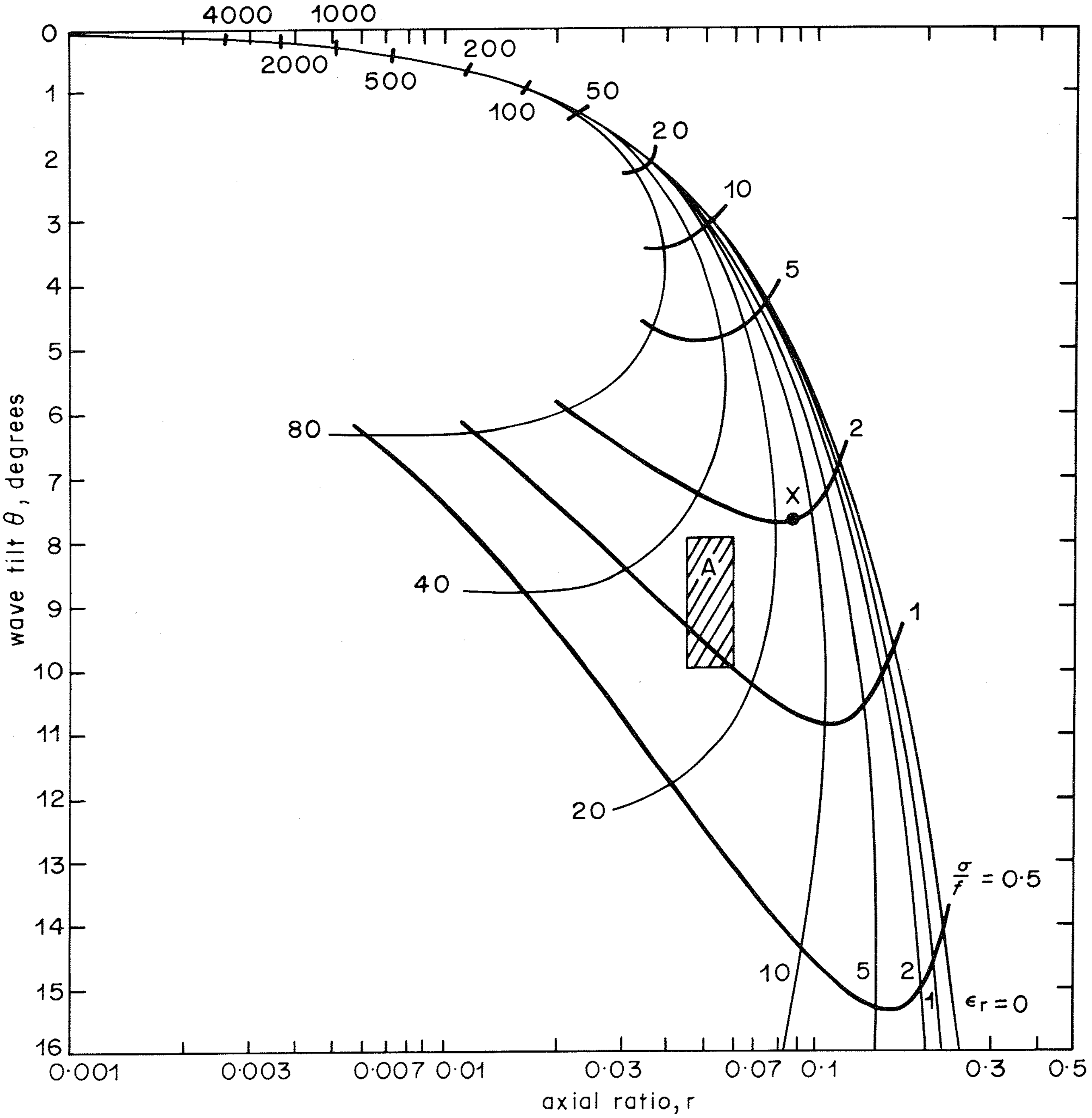

Fig. 1 - Relationship between wave tilt angle, axial ratio of ellipse and the ground constants

━━ σ/f
── ϵ_r

The subscript s denotes surface values at the ground.
d = distance from point of observation.
[] denotes retarded values.
k = propagation constant.
Z_s = surface impedance on ds.

Employing the wave-tilt method as described in previous sections is equivalent to replacing the actual surface in a sufficiently large region about the point of observation by a hypothetical plane. Furthermore, Z_s is supposed constant over the plane and equal to $120\pi\,|E_s/E_n|$.

In going from the surface to the plane the integrands in the above representation will, of course, change in both amplitude and phase but it is reasonable to argue that the most significant effect will be due to the changes in retardation times; these in turn depend on the distances of the surface elements from the point of observation. In principle the orientation of the hypothetical plane can be chosen to minimise the resultant phase changes and hence to give the best approximation that yields an average or effective value of Z_s. In practice it will not be feasible to determine the optimal orientation and hence the reference against which the wave tilt is to be measured. Probably the best that can be done is to take the tangent plane to the ground at the point of observation.

4. Instrumentation

An obvious way to measure tilt and axial ratio of the electric field ellipse is to use a small rotatable dipole mounted on a non-conductive stand a few feet above the ground. The dipole is set up so that its plane of rotation is in the direction of the source and turned until the received signal is at a minimum. The position of the dipole determines the angle of tilt and a further rotation through a right angle will then give the maximum signal. A balanced cable or an unbalanced cable with a good balun transformer is required to connect the dipole to the measuring apparatus.

Alternatively a pair of crossed dipoles could be used to measure the relative amplitude and phase of E_s and E_n directly using a suitable instrument. In this case two cables, one from each dipole, are required and these must be adequately screened from one another to prevent coupling effects.

The stand for the rotatable dipole, or for the crossed dipoles could most conveniently be constructed in tripod form so that in most practical situations the centre of the aerial is approximately situated on the normal to the tangent plane at the point of observation.

5. The effect of measurement errors

The effect of measurement error can be assessed by superimposing a rectangle of uncertainty on the diagram of Figure 1. As an example a rectangle A is shown on the diagram corresponding to an error of ± 1 degree in the tilt and ± 1 dB in the axial ratio. The rectangle may be moved over the diagram showing the sensitivity of the ground constant values to errors of this magnitude in various situations. If the rectangle is centred on a point such as X on the diagram it can be seen that the conductivity and permittivity depend mainly on the measurement accuracy of the tilt angle and axial ratio respectively. Measurement accuracy of this order is essential if useful results are to be obtained.

6. Conclusions

The wave-tilt method of determining electrical ground constants as described in the foregoing has certain drawbacks which may limit its usefulness in practical situations. Field strength predictions normally require effective values of the ground constants that apply over whole areas and take into account the influence of ground irregularities, foliage, buildings etc. These may be obtained by means of ground-wave attenuation methods where the field is sampled at a sufficient number of points on radials from the transmitting source. The wave-tilt method should only be applied where the terrain is flat and free from obstructions and as far away as possible from abrupt changes in the character of the terrain. Even under ideal circumstances the required measurement accuracy is stringent.

7. References

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